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RELATIONS BETWEEN SOIL TYPE AND ROOT FORM OF WESTERN YELLOW PINE SEEDLINGS[1]

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In connection with the study of natural reproduction of western yellow pine, *Pinus ponderosa scopulorum,* at the Fort Valley Station, Flagstaff, Arizona, the writer has been trying during the last two years to correlate the character of root development of young pine seedlings with the types of soil. Observations have been made of 286 root systems distributed among five soil groups and six age classes. It was impossible to make this distribution uniform because of the scarcity of some age classes and the inhibitive character of some soil types. A plant is here considered "one year old" up to the end of the first growing season, and so on.

The area included lies to the south of San Francisco Mountain in Coconino County, Arizona, mainly at the base but extending a short distance up the slope of the mountain, the altitude ranging from 7,300 to 7,700 feet.

In general, the soils on this area are of basaltic origin, though cinder regions of restricted extent are found. The residual soils overlying basalt bed-rock are of a clayey structure, modified by a greater or less quantity of rocks, stones, and gravel. On the adjacent slopes there commonly occurs a much more gravelly colluvial soil. The finest-grained, least gravelly, most compact clay soils are found as alluvial material in basins and valleys. Stony and gravelly areas of alluvial material also occur marking the drainage lines, and forming "alluvial fans"; though, again, these places may contain very fine-grained material, and sometimes the two classes are mixed to form a very heterogeneous soil structure.

Following the work of Mr. J. O. Veatch, of the Bureau of Soils, in this region, fourteen soil types are recognized, which fall into five generalized groups, as follows (6):

1. *Loamy rocky.*—Mellow, dark-colored, loamy soil at surface, moderately high humus content; soil between rocks of outcrop, stone fields, boulder masses, and precipitous slopes; rock sometimes 75-90 percent of surface.

2. *Stony-clayey.*—Stiff, compact, highly retentive clay soils, but modified by a large percentage of stones incorporated in the soil, with a large quantity of loose detached stones scattered over the surface.

3. *Gravelly.*—Loose or loamy, moderately pervious, fairly well aerated

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[1] Presented at the El Paso meeting of the Southwestern Section of the American Association for the Advancement of Science, December, 1920.

surface soil, not crusting or baking to excess when dry; mainly gravelly clay loam with a few scattered stones over the surface (figure 1).

4. *Cindery.*—Pervious gravelly silt loam over cinders; or coarse cinders (figure 3).

5. *Clayey.*—Most compact, least pervious and most poorly aerated soils; deep, highly retentive, and most fertile (figure 2).

The greater part of the area studied is covered by the stony-clayey and the gravelly soils, probably in about equal proportions. The clayey soils constitute a comparatively small part of the total, though somewhat greater than the loamy-rocky which, aside from the mountain slopes, occur chiefly in small points and mounds of rock outcrop. Pines are, however, much more common in this type of soil than in the clay.

The 268 seedlings studied were distributed among the five soil groups as follows:

	Percent
Loamy-rocky	15
Stony-clayey	32
Gravelly	28
Cindery	9
Clayey	16
Total	100

The seedling root types found in the course of this study may be grouped into eight categories, one of which is strictly temporary, no "filiform" roots having been found except in the earlier part of the first growing season:

1. *Filiform* or thread-like; unbranched.
2. *Bifurcate* or forked; branched at a comparatively shallow depth into two main roots.
3. *Muscoid,* or mushroom-like; long laterals near the surface, no smaller laterals below these.
4. *Obconical,* resembling an inverted cone; long laterals near the surface with successively shorter laterals below (figure 1).
5. *Clavate,* or club-shaped; the bulk of the laterals about the lowest third of the main root.
6. *Fusiform,* or spindle shaped; the bulk of the laterals about the center third of the main root, the longest in the middle, those above and below this successively shorter (figure 2).
7. *Cylindrical,* or cylinder shaped; laterals of practically equal length for the entire length of the main root.
8. *Ramified,* or branchy; no definite main root (figure 3).

Of these eight, all but the last are characterized by a definite main root (in the second, by two main roots). The branches of the bifurcate form can, of course, be obconical, clavate, fusiform, or cylindrical. These, however, have all been considered simply bifurcate.

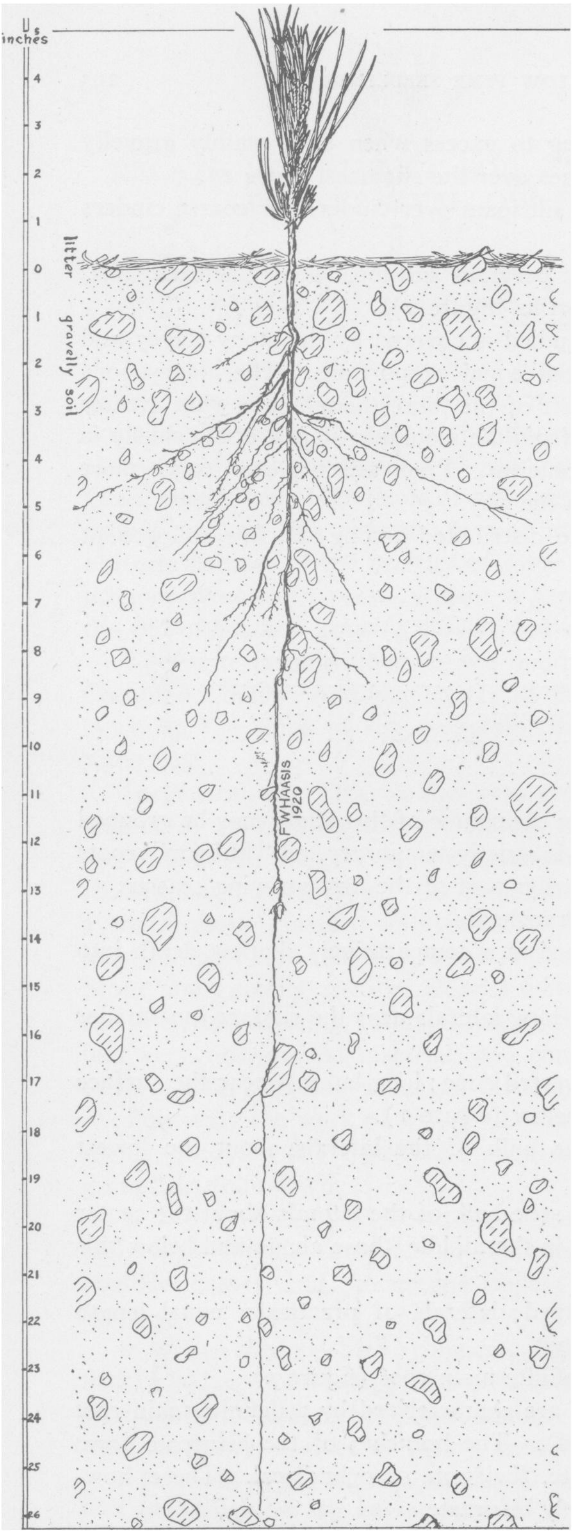

FIG. 1. Four-year old seedling in gravelly soil, obconical form of root.

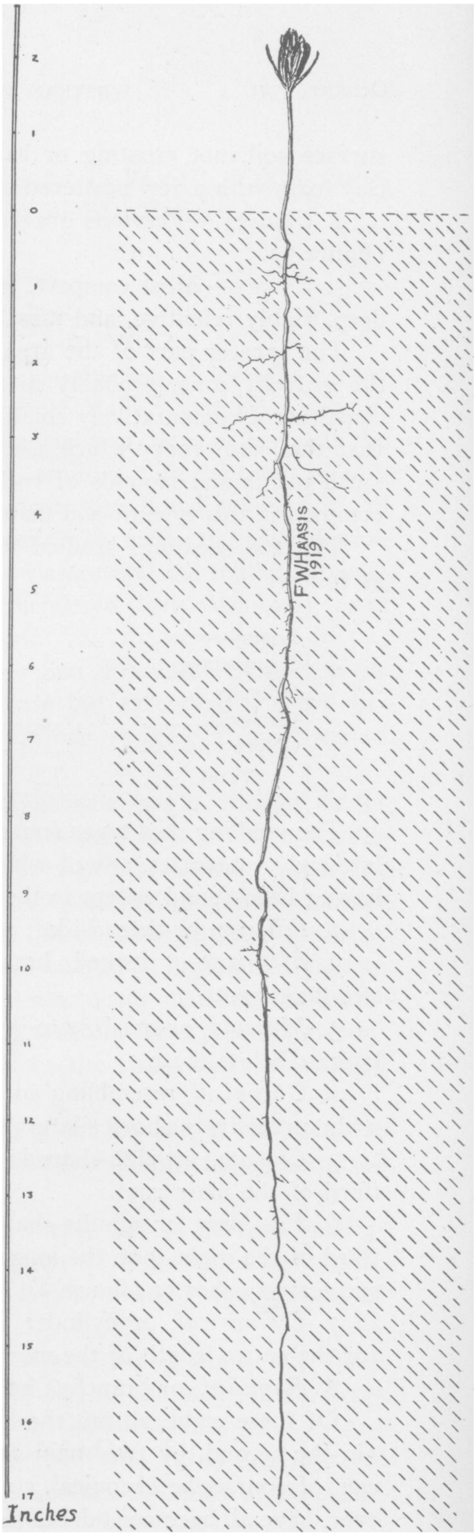

FIG. 2. One-year old seedling, clayey soil, fusiform root. Shows extreme root length, small number of laterals, and absence of "fans."

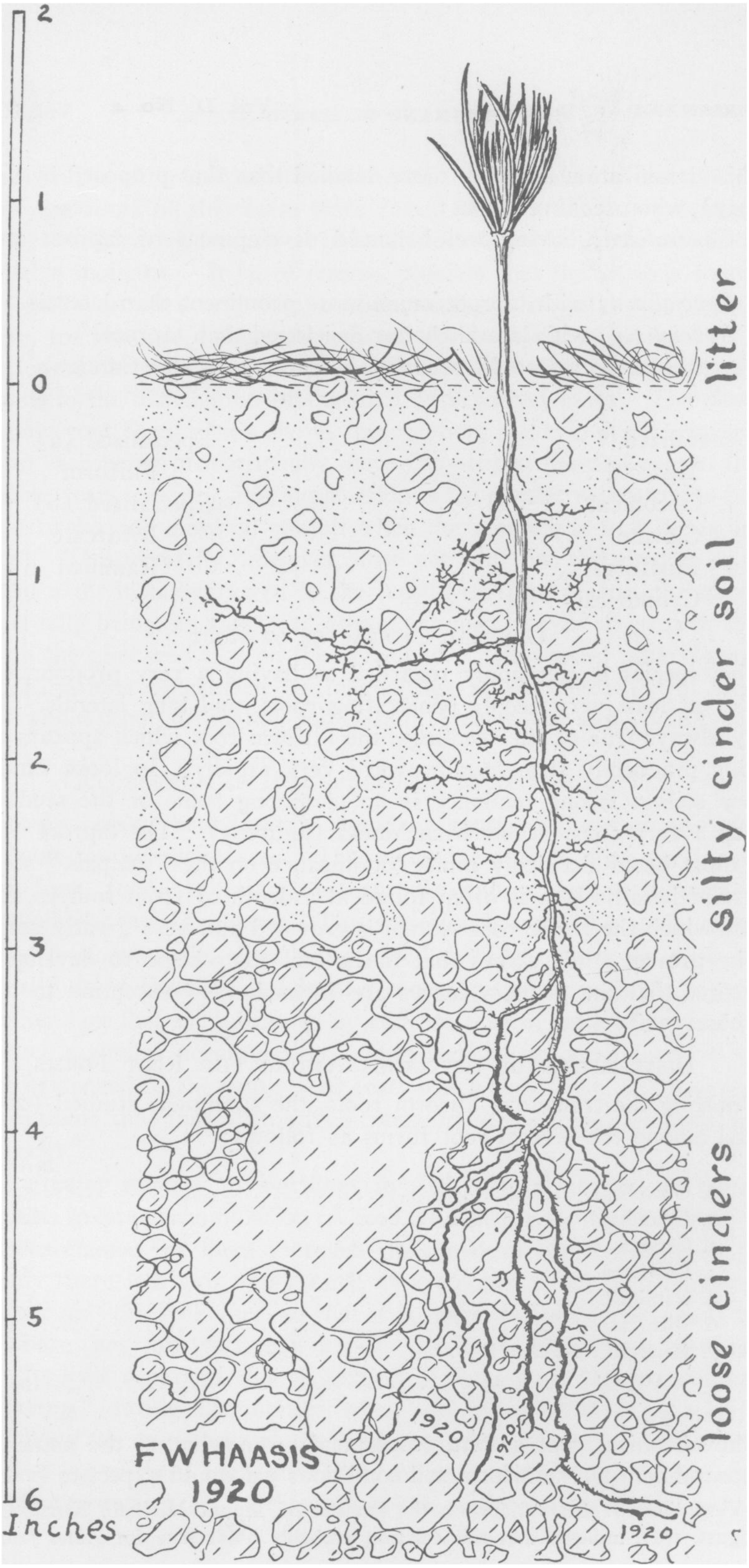

FIG. 3. One-year old seedling, on cindery soil, ramified root form. Shows extreme branchiness and well developed fans. Growth for 1920 indicated by brackets.

This classification is rather more detailed than that proposed by Cannon (2, 1917), who uses three types:

1. *Generalized;* having well-balanced development of taproot and laterals.
2. *Specialized;* with taproot much more prominent than laterals.
3. *Specialized;* with laterals better developed than taproot.

The present forms could probably be grouped under Cannon's types as follows:

Generalized.	Specialized (a)
Muscoid	Filiform
Obconical	Specialized (b)
Clavate	Bifurcate
Fusiform	Ramified
Cylindrical	

General Character of Root

This species is commonly regarded as having a very pronounced taproot, or at least very deeply penetrating roots, and long laterals. This is nearly always true of the seedlings, the filiform root which appears at first growing practically straight downward very rapidly. In loose sandy and cindery soils a strong tendency is noted among some of the seedlings to develop a very considerable branchiness (figure 3). The taproot of older trees must be of decidedly minor significance on the "malpais" soils, for here solid basaltic lava is often found at a depth of from four to six feet, against which the entire root system is crowded and very greatly contorted.

The present study shows that the lateral roots begin to develop at the same time that the primary leaves are formed. No exception to this has been observed.[2]

Distribution of Seedlings Among the Root Forms

Omitting the transitory filiform roots, the specimens studied (205) are divided among the several root forms as follows:

	Percent
1. Obconical	32
2. Cylindrical	28
3. Clavate	19
4. Fusiform	11
5. Ramified	5
6. Bifurcate	3
7. Muscoid	2
Total	100

The obconical root system corresponds somewhat to the conical form of tops: under fairly uniform soil conditions we would expect to find longer branches on the older part of the main root. As a matter of fact, however, some of the roots of this form were found in soils which were most distinctly not uniform, in texture at least, whatever might be the conditions as to available moisture. It is, of course, possible that the various factors in such a soil neutralize and balance one another, irregular distribution of moisture, for instance, being compensated for by variable availability. The proportion of obconical roots occurring in each age class bears a general resemblance to the distribution of the total of branched roots. The obconical is the only root form which shows this relation, the cylindrical, clavate and fusiform each being proportionally more frequent in the first season than in succeeding years. A probable explanation is the greater necessity for prompt response to varying external stimuli when the seedling is first becoming established. This necessity, however, does not confront the plant to so great an extent after it has survived to the second or third season, the obconical form actually being, as suggested above, the normal type of growth toward which all the pine seedlings on the area tend. The several other forms are simply variations occasioned by inequalities in the character of the soil such as would occur within any soil class or even within any single type.

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[2] Very limited observations on the summit of Mount Mitchell, North Carolina, in August, 1921, indicate that this relation probably holds true for *Abies fraseri*.

Occurrence as Influenced by Moisture Supply

In rocky areas where litter is abundant, most seedlings of any age are found next to the rock faces. The seeds themselves were, in the latter part of June, found in fairly uniform distribution but with more seeds nearer the rocks than elsewhere. This variation is ascribable to the fact that, assuming uniform initial distribution, seed falliing on sloping rock would tend to slip down beside it and form a concentration at such places; and to the further fact that seed dropped by rodents feeding on a rock would tend to produce a similar accumulation. That rodents do often feed on top of rocks is evidenced by the empty seed coats which they leave, and it is reasonable to assume that they themselves transport at least part of their supply to the rocks.

The greater number of seedlings in such places may be attributed in part to this greater accumulation of seed, and in part to the fact that there is a better chance for them to reach the moisture of mineral soil. Very commonly there is a gap of as much as a quarter of an inch between the litter layer and the rock face, so that it is much easier for the seeds to get down where they can start than it is in the dense litter mass between the rocks. At least a part of this separation of litter from the rocks is caused by "heaving" during the months when the ground freezes at night and thaws during the day, rocks as much as six inches or more across often being moved up a good inch above the normal surface level. Since most rocks are narrower a few inches above the surface than at the surface, it can readily be seen that the tendency of this movement, unaccompanied as it is by heaving of the litter mat, is to act as a wedge, forcing the litter away from the rock and compacting it, the result being a greater or less opening between rock and litter when the rock settles back to its normal position.

A further possible influence of rocks is to be noted in connection with their underground surface. This is usually covered with a thin coating of clay (the soil most recently derived from the rock), a layer perhaps an eighth of an inch thick but grading off into the normal soil, also filling the rock pores and holding a considerable quantity of moisture not readily lost when the bulk of the soil dries out. The extent to which this moisture is available for plant use has not been determined. The amount is so small that it would be exceedingly difficult to procure samples sufficient for a wilting coefficient test or even for a moisture determination. Roots of pine seedlings and of other plants, however, are frequently found in this clay, penetrating deeply into the rock pores.

Where the litter is less abundant, the greater frequency of seedlings growing adjacent to the rocks is not so evident, possibly because in the absence of thick litter, germination at a distance from the rocks takes place more readily since the seed has a greater chance to reach moist mineral soil.

The growing season of 1919 was unusual in the large amount of precipitation and in its seasonal distribution. A rainy May resulted in considerable quantities of new seedlings throughout the area under observation. Many of these did not last through the subsequent drought, but many others were able to get their roots into contact with a reasonably permanent moisture supply and so held on until the July rains. In a cracked clayey soil few living seedlings were found towards the end of June, but dead seedlings were numerous. Before the July rains the soil was noted as apparently air-dry to a depth of two inches (June 25). This line was very clearly marked, and samples taken at two points gave the following moisture contents, based on dry weight of soil:

	Inches	Percent
A:	0–2	2.5
	2–6	14.0
B:	0–2	5.6
	2–6	16.3

Where the seedling roots were less than two inches long the plants were dead or dying; where they were longer the plants seemed to be still living.

The July rainy season disclosed the fact that only a very small percentage of the available seed had sprouted in May. Conditions were exceptionally favorable, and seedlings appeared in grass, on bare areas, in small washes, on old logs, and in crowns of rosette plants in nearly all soil types. In this case it is evident that litter and logs offered as favorable a place for germination as the soil, simply because of their increased moisture content. The seed in these same situations had failed to sprout six weeks or two months previously.

It is evident that where the normal moisture supply is near the critical minimum, the varying capacities of soils to hold moisture available for plant uses may well constitute limiting factors as between soil types.

Root Character and Soil Group

Since it is obvious that no soil exhibits absolute homogeneity as regards physical structure, chemical composition, and water content, the vast majority of roots will have a certain amount of irregularity, and even those which may, for instance, be described as "growing straight down" will really be longer than the depth of maximum penetration would indicate. This is especially pronounced in soils having such diverse components as clay and gravel. Evidently, the depth to which the roots reach will have considerable influence upon their ability to procure water and plant foods (1, 4). But at the same time these activities are also dependent upon the actual absorbing surface presented, which is largely a function of the number of main roots and laterals and of their total length (4). The absolute length and depth of penetration of the roots of any given plant are, therefore, of little significance when considered by themselves. Probably a more conclusive figure would be the superficial area of the entire root system. However, this presents extreme difficulty of measurement, and it is believed that measurements of length and depth combined with descriptions of the type of root will give results of very satisfactory comparability. This plan has been used in the present study. As a matter of fact, however, the species under consideration is marked by a root of very constant general type, a main vertical root with a number of laterals of different lengths and variously placed; and, therefore, we may make some direct comparisons, considering merely root length and depth.

Waterman and Weaver have pointed out in recent publications that the type and the flexibility of root development are specific characters, and that there is sometimes within a species very pronounced variation dependent upon the difference in site (7, 8). Cannon has found that some species are unable to survive where the taproot cannot be developed, while others, with a "generalized" root system, can readily adapt themselves to varying conditions (2, 1913). Clements states that a deep-seated root system is characteristic of most xerophytes (3). Weaver notes that the forest-floor herbs and shrubs studied were mainly shallow-rooted and that the same superficiality held true for many of the roots of even tree dominants (8).

The Fort Valley work has developed that the roots are longer in clayey soils than in stony or loamy, and that branching is very pronounced in loose, cindery soils. In extremely rocky areas, of course, there is a great deal of distortion due to the interference of the rock fragments, and the actual depth is frequently very appreciably lessened. The above statement, however, refers to plants whose growth has not been so diverted. Root length and depth are, furthermore, found to be greater in gravelly than in stony-clayey or loamy-rocky soils. In the order of the length and depth of root the five soil groups may be arranged as follows, the roots in the clayey soil averaging longest:

1. Clayey
2. Gravelly
3. Stony-clayey
4. Cindery
5. Loamy-rocky

Wilting coefficient tests have yielded the following comparisons:

1. Stony-clayey (greatest).
2. Loamy-rocky.
3. Clayey.
4. Gravelly.
5. Cindery (least).

There is little or no obvious connection between this series and the root length data. Probably the very close texture of the clayey soil results in a rapid drying-out of the upper layers due to the well-developed capillary continuity, so that those individuals which did not develop downwards very rapidly, overtaken by the drying soil, soon died, and thus were not included in the study. The stony-clayey soils, also, would probably have similar capillary conditions but for the admixture of stone. It is possible that evaporation is retarded by that same tenacity which results in a high wilting coefficient. This is most likely so much more pronounced in these soils than in the clayey because the elements of the latter have been re-arranged and sorted, to a greater or less extent, while the stony-clayey soils are formed in place. Perhaps the thin layer of moister soil about the rocks and stones in the stony-clayey and the loamy-rocky soils enables plants to get along without excessively deep roots. The many small stones and pebbles in the gravelly group, on the other hand, will result in a tendency for the soil to lose considerable water through percolation. This might also be expected in the cinder soils, but a closer inspection shows that the structure of the individual cinders is exceedingly porous, so that, while the capillary continuity between particles is slight, if a plant can get enough lateral roots in contact with the separate cinders it will be able to withdraw a great deal of the moisture contained in these small "sponges." It is very significant that the cinder soils have the lowest wilting coefficient. Towards the end of the 1919 growing season many plants had developed lateral roots which penetrated well into the pores of the cinder fragments. Apparently those seedlings which had developed a greater number of fans and a more elaborate ramification in 1919 were the ones which were growing better in the spring of 1920.

The data obtained show that in the loamy-rocky group laterals are numerous, sometimes occurring at the top of the main root, sometimes at the lower end, and sometimes throughout its length. The typical obconical form, while well represented, is not predominant, both cylindrical and clavate each occurring half again as frequently. Forms with more than one main root are found, though these are definitely in the minority.

The seedlings in the stony-clayey and in the gravelly soils exhibit very similar proportions of each form. Laterals are numerous, especially at the top, while division into more than one main root is somewhat less common than in the loamy-rocky, the ramified form being entirely lacking in the stony-clayey and the bifurcate nearly so in both stony-clayey and gravelly.

As has been mentioned, branching is very common in the cinder soils, nearly forty percent of the seedlings from these soils having roots of this form.

In the clayey group the clavate form greatly predominates and is commoner than in the other soil groups; there is no dividing into more than one main root. In the first season the clay soil roots exhibit a strong tendency to extend straight down into the soil, forming a long taproot with few and short laterals. While vertical main roots occur in the other types, the length is not so great and the laterals are inclined to be longer and more numerous. Extreme branchiness was not observed in the clay soils. The obconical, fusiform, and cylindrical are most numerously represented in the stony-clayey and the gravelly soils. The muscoid form is infrequent in any soil.

The primary roots of plants exhibit, in general, positive geotropism, rather than negative phototropism which is not evident in the common type of root, while the laterals may be oblique or nearly horizontal ("apogeotropic" or "plagiotropic") (5). Of course, an obstacle in a root's path will cause decided variations from these normals. The growing tip's sensitiveness to contact results in the root's turning aside when impenetrable substances are encountered (3). Sometimes a primary root will run for a considerable distance obliquely along the surface of a large rock. In the case of a smaller fragment, it will continue obliquely until free of the stone and able to proceed in a vertical direction. It is probable that this is frequently modified by the hydrotropic properties common in roots, so that when a growing tip enters the moist clayey soil about a rock fragment (previously discussed), it will continue to grow close to the obstruction even after it is free to reassume the vertical position, the hydrotropism in this case being stronger than geotropism. This requires further study before a positive statement can be made. Of course, on a horizontal surface of rock or hardpan, flattening out must occur. Occasionally a root will describe a spiral in a pore of vesicular rock, forming a succession of loops; while roots are quite frequently found entering these pores to a greater or less distance. Apparently, in both these instances the available moisture is the controlling factor.

Fan-like modifications, the "feather-roots" (Fjäder rot), of Swedish botanists, occurred on roots of nearly a third of the branched forms studied (figure 3). This is apparently connected with branchiness in general, the largest percentages occurring in the most branchy forms, bifurcate and ramified.

It has been found that for the same top development, the root development is greater in the more clayey soils than in the loamy-rocky (figures 2 and 3). It is to be noted that this series is almost exactly the opposite of that found by comparing the root lengths alone.

Soils Limiting Distribution

The natural boundaries of plant ranges are obviously determined by the ability of a given species to live on one side of that boundary and its inability to live on the other side. The biological character of any given species is a complex of a number of hereditary characteristics and it is often very difficult or even impossible to designate any one particular factor in the plant's reactions which results in limiting the distribution of that species.

However, it can be said with reasonable assurance that, for western yellow pine in the area under consideration, the limiting soil types are the clayey and the cindery. While pine is found upon cinder areas, when these are combined with a south slope the pine begins to disappear. Pine is also found on clayey flats, but these are more commonly given over to grass with pine in the nature of an invader. This condition may be due in part to the grazing in the parks; but it is by no means the only factor concerned, many deaths of young seedlings occurring from both drying and frost heaving. Evidently in the case of the cinders, it is mainly a question of deficient moisture supply. Of course, other factors, such as excessive heat, may be involved.

It is to be noted that the root development in these two diverse types of limiting soil is extreme in both instances: the longest roots and the fewest laterals and "fans" are found in one (figure 2), the greatest branchiness and most abundant fans in the other (figure 3).

Summary and Conclusions

Observations were made of 268 western yellow pine seedling roots, falling into eight general forms (one transitory), and occurring in five classes of soil in the vicinity of Fort Valley Experiment Station, Flagstaff, Arizona. It is found that the more clayey the soil the longer is the root and the smaller the ratio between top and root; the more loamy the soil the shorter is the root and the greater the T/R ratio. That is, the greater the available moisture the shorter is the root and the greater is the ratio between top and root. This coincides with Weaver's observations (**8**).

Branching is developed to the greatest extent in cindery soils and least in clayey soils. Laterals are numerous in the loamy-rocky soils, moderately so in stony-clayey and gravelly. Root fans occur as an extreme form of branchiness. Wilting coefficient tests showed the stony-clayey soil to hold most unavailable water and the cindery soil least.

The limiting soil types for this species in this region are the clayey and the cindery; the plants in the former being characterized by the longest roots and the fewest laterals and fans, in the latter by the greatest branchiness and most abundant fans—both extremes of development.

BIBLIOGRAPHY

1. **Bowman, I.**
   '14 Forest Physiography.
2. **Cannon, W. A.**
   '13 Some Relations between Root Characters, Ground Water and Species Distribution. Sci. n. s. 37, no. 950.
   '17 The Root Systems of Desert Plants. Pub. Carn. Inst. Wash., No. 131; cited by Markle, M. S. Root Systems of Certain Desert Plants. Bot. Gaz., vol. 64, no. 3.
3. **Clements, F. E.**
   '07 Plant Physiology and Ecology.
4. **Hilgard, E. W.**
   '07 Soils.
5. **Palladin, V. I.** (Livingston, B. E., *Tr.*)
   '17 Plant Physiology.
6. **Veatch, J. O.**
   '19 Unpublished mss.
7. **Waterman, W. G.**
   '19 Development of Root Systems under Dune Conditions. Bot. Gaz. 68, No. 1.
8. **Weaver, J. E.**
   '19 The Ecological Relations of Roots. Pub. Carn. Inst. Wash. 286.